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Power Quality Monitoring

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Many power quality problems are caused by inadequate wiring or improper grounding. These problems can be detected by simple examination of the wiring and grounding systems. Another large population of power quality problems can be solved by spotchecks of voltage, current, or harmonics using hand held meters. Some problems, however, are intermittent and require longer-term monitoring for solution.

Long-term power quality monitoring is largely a problem of data management. If an RMS value of voltage and current is recorded each electrical cycle, for a three-phase system, about 6 gigabytes of data will be produced each day. Some equipment is disrupted by changes in the voltage waveshape that may not affect the rms value of the waveform. Recording the voltage and current waveforms will result in about 132 gigabytes of data per day. While modern data storage technologies may make it feasible to record every electrical cycle, the task of detecting power quality problems within this mass of data is daunting indeed.

Most commercially available power quality monitoring equipment attempts to reduce the recorded data to manageable levels. Each manufacturer has a generally proprietary data reduction algorithm. It is critical that the user understand the algorithm used in order to properly interpret the results.

33.1 Selecting a Monitoring Point

Power quality monitoring is usually done to either solve an existing power quality problem, or to determine the electrical environment prior to installing new sensitive equipment. For new equipment, it is easy to argue that the monitoring equipment should be installed at the point nearest the point of connection of the new equipment. For power quality problems affecting existing equipment, there is frequently pressure to determine if the problem is being caused by some external source, i.e., the utility. This leads to the installation of monitoring equipment at the service point to try to detect the source of the problem. This is usually not the optimum location for monitoring equipment. Most studies suggest that 80% of power quality problems originate within the facility. A monitor installed on the equipment being affected will detect problems originating within the facility, as well as problems originating on the utility. Each type of event has distinguishing characteristics to assist the engineer in correctly identifying the source of the disturbance.

33.2 What to Monitor

At minimum, the input voltage to the affected equipment should be monitored. If the equipment is single phase, the monitored voltage should include at least the line-to-neutral voltage and the neutral-to-ground voltages. If possible, the line-to-ground voltage should also be monitored. For three-phase equipment, the voltages may either be monitored line to neutral, or line to line. Line-to-neutral voltages are easier to understand, but most three-phase equipment operates on line-to-line voltages. Usually, it is preferable to monitor the voltage line to line for three-phase equipment.

If the monitoring equipment has voltage thresholds which can be adjusted, the thresholds should be set to match the sensitive equipment voltage requirements. If the requirements are not known, a good starting point is usually the nominal equipment voltage plus or minus 10%.

In most sensitive equipment, the connection to the source is a rectifier, and the critical voltages are DC. In some cases, it may be necessary to monitor the critical DC voltages. Some commercial power quality monitors are capable of monitoring AC and DC simultaneously, while others are AC only.

It is frequently useful to monitor current as well as voltage. For example, if the problem is being caused by voltage sags, the reaction of the current during the sag can help determine the source of the sag. If the current doubles when the voltage sags 10%, then the cause of the sag is on the load side of the current monitor point. If the current increases or decreases 10–20% during a 10% voltage sag, then the cause of the sag is on the source side of the current monitoring point.

Sensitive equipment can also be affected by other environmental factors such as temperature, humidity, static, harmonics, magnetic fields, radio frequency interference (RFI), and operator error or sabotage. Some commercial monitors can record some of these factors, but it may be necessary to install more than one monitor to cover every possible source of disturbance.

It can also be useful to record power quantity data while searching for power quality problems. For example, the author found a shortcut to the source of a disturbance affecting a wide area by using the power quantity data. The recordings revealed an increase in demand of 2500 KW immediately after the disturbance. Asking a few questions quickly led to a nearby plant with a 2500 KW switched load that was found to be malfunctioning.

33.3 Selecting a Monitor

Commercially available monitors fall into two basic categories: line disturbance analyzers and voltage recorders. The line between the categories is becoming blurred as new models are developed. Voltage recorders are primarily designed to record voltage and current stripchart data, but some models are able to capture waveforms under certain circumstances. Line disturbance analyzers are designed to capture voltage events that may affect sensitive equipment. Generally, line disturbance analyzers are not good voltage recorders, but newer models are better than previous designs at recording voltage stripcharts.

In order to select the best monitor for the job, it is necessary to have an idea of the type of disturbance to be recorded, and an idea of the operating characteristics of the available disturbance analyzers. For example, a common power quality problem is nuisance tripping of variable speed drives. Variable speed drives may trip due to the waveform disturbance created by power factor correction capacitor switching, or due to high or low steady state voltage, or, in some cases, due to excessive voltage imbalance. If the drive trips due to high voltage or waveform disturbances, the drive diagnostics will usually indicate an overvoltage code as the cause of the trip. If the voltage is not balanced, the drive will draw significantly unbalanced currents. The current imbalance may reach a level that causes the drive to trip for input overcurrent. Selecting a monitor for variable speed drive tripping can be a challenge. Most line disturbance analyzers can easily capture the waveshape disturbance of capacitor switching, but they are not good voltage recorders, and may not do a good job of reporting high steady state voltage. Many line disturbance analyzers cannot capture voltage unbalance at all, nor will they respond to current

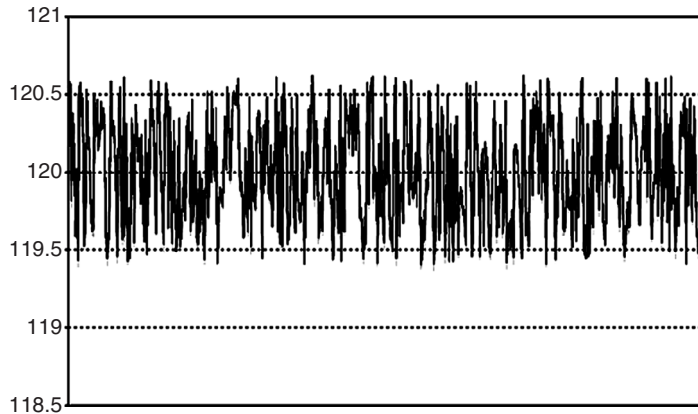


FIGURE 33.1 RMS voltage stripchart, taken cycle by cycle.

events unless there is a corresponding voltage event. Most voltage and current recorders can easily capture the high steady state voltage that leads to a drive trip, but they may not capture the capacitor switching waveshape disturbance. Many voltage recorders can capture voltage imbalance, current imbalance, and some of them will trigger a capture of voltage and current during a current event, such as the drive tripping off.

To select the best monitor for the job, it is necessary to understand the characteristics of the available monitors. The following sections will discuss the various types of data that may be needed for a power quality investigation, and the characteristics of some commercially available monitors.

33.3.1 Voltage

The most commonly recorded parameter in power quality investigations is the RMS voltage delivered to the equipment. Manufacturers of recording equipment use a variety of techniques to reduce the volume of the data recorded. The most common method of data reduction is to record Min/Max/Average data over some interval. Figure 33.1 shows a strip chart of rms voltages recorded on a cycle-by-cycle basis. Figure 33.2 shows a Min/Max/Average chart for the same time period. A common recording period is 1 week. Typical recorders will use a recording interval of 2–5 minutes. Each recording interval will produce

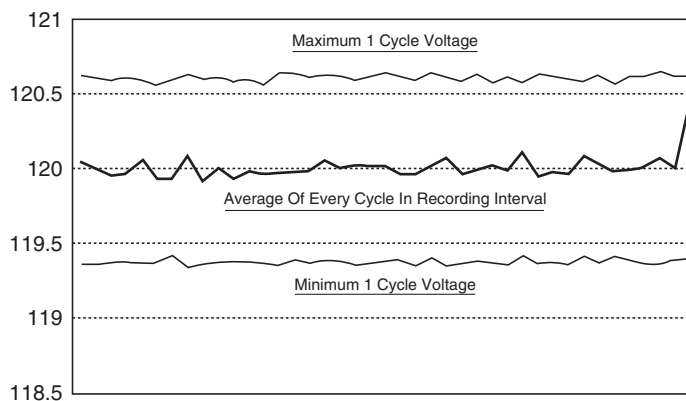


FIGURE 33.2 Min/Max/Average stripchart, showing the minimum single cycle voltage, the maximum single cycle voltage, and the average of every cycle in a recording interval. Compare to the Fig. 33.1 stripchart data.

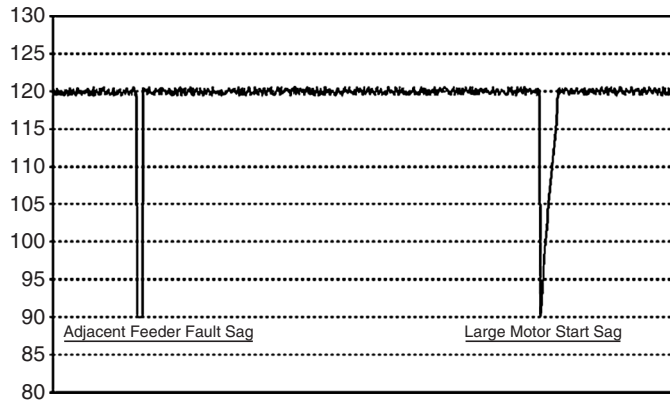


FIGURE 33.3 Cycle-by-cycle rms stripchart showing two voltage sags. The sag on the left is due to an adjacent feeder fault on the supply substation, and the sag on the right is due to a large motor start. Note the difference in the voltage profile during recovery.

three numbers: the rms voltage of the highest 1 cycle, the lowest 1 cycle, and the average of every cycle during the interval. This is a simple, easily understood recording method, and it is easily implemented by the manufacturer. There are several drawbacks to this method. If there are several events during a recording interval, only the event with the largest deviation is recorded. Unless the recorder records the event in some other manner, there is no time-stamp associated with the events, and no duration available. The most critical deficiency is the lack of a voltage profile during the event. The voltage profile provides significant clues to the source of the event. For example, if the event is a voltage sag, the minimum voltage may be the same for an event caused by a distant fault on the utility system, and for a nearby large motor start. For the distant fault, however, the voltage will sag nearly instantaneously, stay at a fairly constant level for 3–10 cycles, and almost instantly recover to full voltage, or possibly a slightly higher voltage if the faulted section of the utility system is separated. For a nearby motor start, the voltage will drop nearly instantaneously, and almost immediately begin a gradual recovery over 30–180 cycles to a voltage somewhat lower than before. Figure 33.3 shows a cycle-by-cycle recording of a simulated adjacent feeder fault, followed by a simulation of a voltage sag caused by a large motor start. Figure 33.4 shows a Min/Max/Average recording of the same two events. The events look quite

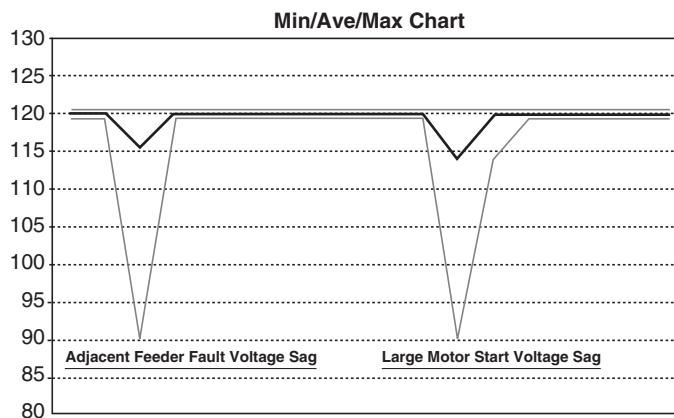


FIGURE 33.4 Min/Max/Average stripchart of the same voltage sags as Fig. 33.3. Note that both sags look almost identical. Without the recovery detail found in Fig. 33.3, it is difficult to determine a cause for the voltage sags.

similar when captured by the Min/Max/Average recorder, while the cycle-by-cycle recorder reveals the difference in the voltage recovery profile.

Some line disturbance analyzers allow the user to set thresholds for voltage events. If the voltage exceeds these thresholds, a short duration stripchart is captured showing the voltage profile during the event. This short duration stripchart is in addition to the long duration recordings, meaning that the engineer must look at several different charts to find the needed information.

Some voltage recorders have user-programmable thresholds, and record deviations at a higher resolution than voltages that fall within the thresholds. These deviations are incorporated into the stripchart, so the user need only open the stripchart to determine, at a glance, if there are any significant events. If there are events to be examined, the engineer can immediately “zoom in” on the portion of the stripchart with the event.

Some voltage recorders do not have user-settable thresholds, but rather choose to capture events based either on fixed default thresholds or on some type of significant change. For some users, fixed thresholds are an advantage, while others are uncomfortable with the lack of control over the meter function. In units with fixed thresholds, if the environment is normally somewhat disturbed, such as on a welder circuit at a motor control center, the meter memory may fill up with insignificant events and the monitor may not be able to record a significant event when it occurs. For this reason, monitors with fixed thresholds should not be used in electrically noisy environments.

33.3.2 Voltage Waveform Disturbances

Some equipment can be disturbed by changes in the voltage waveform. These waveform changes may not significantly affect the rms voltage, yet may still cause equipment to malfunction. An rms-only recorder may not detect the cause of the malfunction. Most line disturbance analyzers have some mechanism to detect and record changes in voltage waveforms. Some machines compare portions of successive waveforms, and capture the waveform if there is a significant deviation in any portion of the waveform. Others capture waveforms if there is a significant change in the rms value of successive waveforms. Another method is to capture waveforms if there is a significant change in the voltage total harmonic distortion (THD) between successive cycles.

The most common voltage waveform change that may cause equipment malfunction is the disturbance created by power factor correction capacitor switching. When capacitors are energized, a disturbance is created that lasts about 1 cycle, but does not result in a significant change in the rms voltage. Figure 33.5 shows a typical power factor correction capacitor switching event.

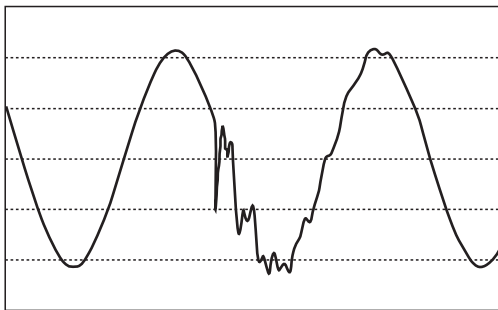


FIGURE 33.5 Typical voltage waveform disturbance caused by power factor correction capacitor energization.

33.3.3 Current Recordings

Most modern recorders are capable of simultaneous voltage and current recordings. Current recordings can be useful in identifying the cause of power quality disturbances. For example, if a 20% voltage sag (to 80% of full voltage) is accompanied by a small change in current (plus or minus about 30%), the cause of the voltage sag is usually upstream (toward the utility source) of the monitoring point. If the sag is accompanied by a large increase in current (about 100%), the cause of the sag is downstream (toward the load) of the monitoring point. Figure 33.6 shows the rms voltage and current captured during a motor start downstream of the monitor. Notice the large current increase during starting and the corresponding small decrease in voltage.

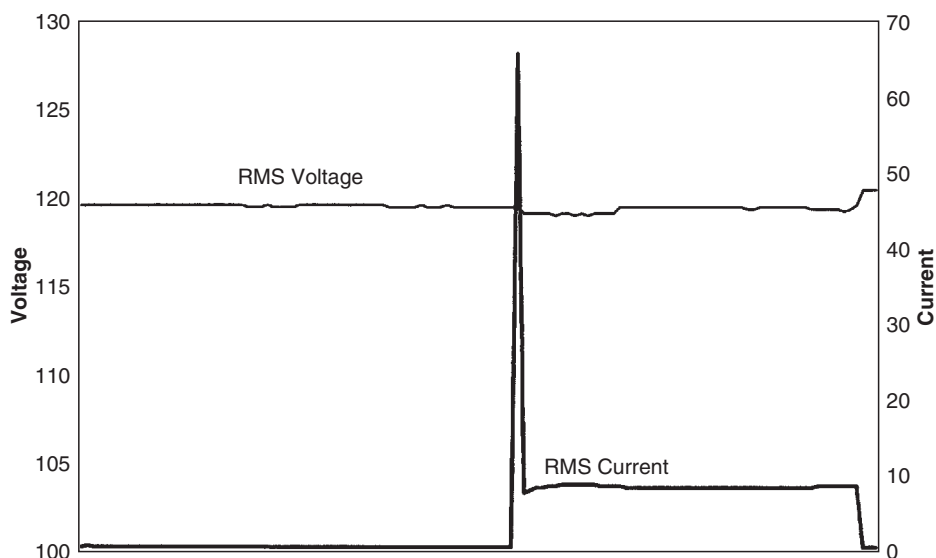


FIGURE 33.6 RMS stripcharts of voltage and current during a large current increase due to a motor start downstream of the monitor point.

Some monitors allow the user to select current thresholds that will cause the monitor to capture both voltage and current when the current exceeds the threshold. This can be useful for detecting over- and under-currents that may not result in a voltage disturbance. For example, if a small, unattended machine is tripping off unexpectedly, it would be useful to have a snapshot of the voltage and current just prior to the trip. A threshold can be set to trigger a snapshot when the current goes to zero. This snapshot can be used to determine if the input voltage or current was the cause of the machine trip.

33.3.4 Current Waveshape Disturbances

Very few monitors are capable of capturing changes in current waveshape. It is usually not necessary to capture changes in current waveshape, but in some special cases this can be useful data. For example, inrush current waveforms can provide more useful information than inrush current rms data. [Figure 33.7](#) shows a significant change in the current waveform when the current changes from zero to nearly 100 amps peak. The shape of the waveform, and the phase shift with respect to the voltage waveform, confirm that this current increase was due to an induction motor start. [Figure 33.7](#) shows the first few cycles of the event shown in [Fig. 33.6](#).

33.3.5 Harmonics

Harmonic distortion is a growing area of concern. Many commercially available monitors are capable of capturing harmonic snapshots. Some monitors have the ability to capture harmonic stripchart data. In this area, it is critical that the monitor produce accurate data. Some commercially available monitors have deficiencies in measuring harmonics. Monitors generally capture a sample of the voltage and current waveforms, and perform a Fast Fourier Transform to produce a harmonic spectrum. According to the Nyquist Sampling Theorem, the input waveform must be sampled at least twice the highest frequency that is present in the waveform. Some manufacturers interpret this to mean the highest frequency of interest, and adjust their sample rates accordingly. If the input signal contains a frequency that is above the maximum frequency that can be correctly sampled, the high frequency signal may be “aliased,” that is, it may be incorrectly identified as a lower frequency harmonic. This may lead the engineer to search for a

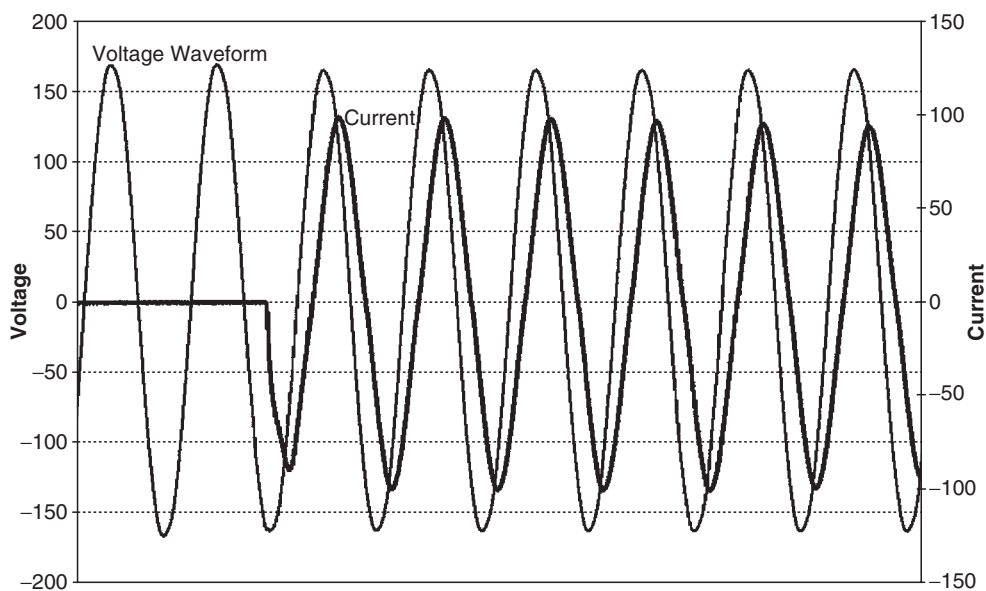


FIGURE 33.7 Voltage and current waveforms for the first few cycles of the current increase illustrated in [Fig. 33.6](#).

solution to a harmonic problem that does not exist. The aliasing problem can be alleviated by sampling at higher sample rates, and by filtering out frequencies above the highest frequency of interest. The sample rate is usually found in the manufacturer's literature, but the presence of an antialiasing filter is not usually mentioned in the literature.

33.3.6 Flicker

Some users define flicker as the voltage sag that occurs when a large motor starts. Other users regard flicker as the frequent, small changes in voltage that occur due to the operation of arc furnaces, welders, chippers, shredders, and other varying loads. Nearly any monitor is capable of adequately capturing voltage sags due to occasional motor starts. The second definition of flicker is more difficult to monitor. In the absence of standards, several manufacturers have developed proprietary "flicker" meters. In recent years, an effort has been made to standardize the definition of "flicker," and to standardize the performance of flicker meters. At the time of this writing, several monitor manufacturers are attempting to incorporate the standardized flicker function into their existing products.

33.3.7 High Frequency Noise

Sensitive electronic equipment can be susceptible to higher frequency signals imposed on the voltage waveform. These signals may be induced on the conductors by sources such as radio transmitters or arcing devices such as fluorescent lamps, or they may be conductively coupled by sources such as power line carrier energy management systems. A few manufacturers include detection circuitry for high frequency signals imposed on the voltage waveform.

33.3.8 Other Quantities

It may be necessary to find a way to monitor other quantities that may affect sensitive equipment. Examples of other quantities are temperature, humidity, vibration, static electricity, magnetic fields, fluid flow, and air flow. In some cases, it may also become necessary to monitor for vandalism or

sabotage. Most power quality monitors cannot record these quantities, but other devices exist that can be used in conjunction with power quality monitors to find a solution to the problem.

33.4 Summary

Most power quality problems can be solved with simple hand-tools and attention to detail. Some problems, however, are not so easily identified, and it may be necessary to monitor to correctly identify the problem. Successful monitoring involves several steps. First, determine if it is really necessary to monitor. Second, decide on a location for the monitor. Generally, the monitor should be installed close to the affected equipment. Third, decide what quantities need to be monitored, such as voltage, current, harmonics, and power data. Try to determine the types of events that can disturb the equipment, and select a meter that is capable of detecting those types of events. Fourth, decide on a monitoring period. Usually, a good first choice is at least one business cycle, or at least 1 day, and more commonly, 1 week. It may be necessary to monitor until the problem recurs. Some monitors can record indefinitely by discarding older data to make space for new data. These monitors can be installed and left until the problem recurs. When the problem recurs, the monitoring should be stopped before the event data is discarded.

After the monitoring period ends, the most difficult task begins — interpreting the data. Modern power quality monitors produce reams of data during a disturbance. Data interpretation is largely a matter of experience, and Ohm's law. There are many examples of disturbance data in books such as *The BMI Handbook of Power Signatures, Second Edition*, and the *Dranetz Field Handbook for Power Quality Analysis*.